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Transpirational drying of limbed and unlimbed lodgepole pine and Douglas-fir with controlled precipitation

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TRANSPIRATIONAL DRYING OF LIMBED AND UNLIMBED LODGEPOLE PINE AND DOUGLAS-FIR WITH CONTROLLED PRECIPITATION

by

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Transpirational drying of limbed and unlimbed lodgepole pine and Douglas-fir with controlled precipitation (41 pages)

Director: Dr. Edwin J. Burke Edwin J Burke

The 1973 world energy crisis played a major role in redirecting countries' views to the use of wood as means of combating energy shortages. However, to improve current utilization practices, one basic question must be answered: what are the optimum drying times of whole trees used to produce fuel in order to realize maximum economic returns for users and suppliers? This study was designed to answer the above question using a complex statistical analysis of the transpirational drying of two commercially important fuel species in the Inland Northwest.

Twelve trees each of lodgepole pine (Pinus contorta Dougl. ex Laud.) and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) between six to eight inches diameter at breast height (DBH) were harvested. For each species, six of the trees were limbed while the six others remained unlimbed. In order to determine the potential interactive effects of foliage and precipitation on transpirational drying, two structures with transparent roofs were erected, housing three limbed and three unlimbed trees of each species. In addition, one of the structures contained a sprinkler system designed to artificially produce a quarter inch of precipitation weekly. Finally, the moisture content of the trees were monitored for six weeks. Mean moisture contents were compared for various main effects (treatments) and their interactions through analysis of variance (ANOVA). This was supplemented by a graphical display of moisture contents versus dates to show the drying rates of the various treatments. Finally, the Optimum Chipping Period (OCP)--or the period of time from harvest to the point where desorption of water from the log through transpirational drying is greater than or equal to absorption of precipitation by the log--was determined for each treatment. Results show that regardless of species, watered or unwatered, the unlimbed trees dried faster than those that were limbed. Further, the unlimbed trees attained their OCP one week after harvest, while the limbed trees reached their OCP between one and two weeks after harvest.

ACKNOWLEDGEMENTS

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Finally, I use this opportunity to thank my parents, Mr. and Mrs. I. U. Uzoh as well as my brothers and sisters, without whose encouragement I would not have been able to further my education.

All errors found in this thesis remain solely my responsibility.

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INTRODUCTION

The concept of using wood as a source of energy is widespread, the practice as old as the forest products industry itself (Garrett 1985). The 1973 world energy crisis played a major role in redirecting countries' views of their renewable natural resources, particularly wood, as a means of combating energy shortages (Kelsey et al. 1979). In the Northern Rocky Mountain region, whole-tree chips produced from thinnings and logging slash have become an important resource for hogfuel. For example, in the Missoula area, several operations are producing whole-tree chips, primarily for use by Stone Container Corporation's Frenchtown mill linerboard energy production operations.

Further, the drying of wood before use has many advantages, some of which are: (a) increased heat value, (b) lower transportation costs, (c) increased furnace capacity and efficiency, (d) reduced quality of stack grasses, and (e) reduced particulate emissions (Springer 1980, Walters 1979).

Prediction of prime harvest time and the optimal transpirational drying periods are essential to wood production. If businesses involved in hogfuel production can make those predictions, then they will increase potential for high productivity.

The primary objective of this study was to predict the "Optimum Chipping Period" or the period of time from harvest to the point where desorption of water from the log through transpirational drying is greater than or equal to absorption of precipitation by the log. Furthermore, to provide important technical information to businesses involved in hogfuel productions and wood-fired electric generating systems.

PROBLEM STATEMENT

To improve current practice, one basic question had to be answered: what are the optimum drying times for realization of maximum economic returns for users and suppliers of hogfuel? Incontrovertibly, businesses involved in hogfuel production as well as wood-fired electric generating systems must provide practical answers to the above question in order to enjoy a higher level of productivity.

This thesis was designed to answer the question: "What are the optimum drying times for the realization of maximum economic returns for users and suppliers?" It addressed the above question by studying the transpirational drying process, which is the fastest and easiest method by which delayed processing of felled trees can reduce their moisture content (Garrett 1985, McMinn 1986).

OBJECTIVE

The objective of this study is to determine the effects of precipitation and foliage on transpirational drying. It will provide information for enhanced understanding of the drying characteristics of limbed and unlimbed lodgepole pine and Douglas-fir. In essence, research efforts in these regards focused on the concept of "Optimum Chipping Period" or the elapsed time since harvesting necessary to minimize the risk of rewetting while maximizing dryness for realization of maximum economic returns for users and suppliers. This point is the most profitable time to chip-up the logs because beyond this point the logs will start picking up moisture--hence, leaving the logs longer in the field and tying down capital.

HYPOTHESIS

Based on the study described hereunder, the position here was that there is no emperical effects between the process of controlled precipitation and that of transpirational drying.

All references to statistically significant differences between means are denoted at the 5 percent level--that is, the likelihood of rejecting null hypothesis when null hypothesis is true is five times out of a hundred.

HYPOTHESIS TO BE TESTED

There is no difference in mean moisture content between

1. Watered unlimbed Douglas-fir versus unwatered unlimbed Douglas-fir.
2. Watered unlimbed lodgepole pine versus unwatered unlimbed lodgepole pine.
3. Watered limbed Douglas-fir versus unwatered limbed Douglas-fir.

4. Watered limbed lodgepole pine versus unwatered limbed lodgepole pine.

REVIEW

Undoubtedly, in all primary manufacture of forest products, the drying of wood accounts for sixty to seventy percent of the energy used in lumber and veneer manufacture. The parameter depends on a number of factors; the amount of water in the fuel evaporated into the atmosphere being by far the biggest factor (Comstock 1976). The lower the moisture content of the stem and branches, the higher the net BTU yield (Comstock 1976, Corder 1976, Rogers 1981, Springer 1980, Wells 1984), therefore, the higher the price paid per ton of wood delivered (Wells 1984). Also, low fuel moisture, minimal amount of excess combustion air and low stack temperature result in high heat recovery from fuel (Corder 1976), and have been the topics of recent research activities (Rogers 1981). Studies have estimated the impact of low moisture content of stem and branches on cost, efficiency of transportation, handling and use at seven to twenty-five percent (Corder 1976, Garrett 1985, Sherwood 1978).

Transpirational drying is the drying of a felled tree with the crown intact. The moisture loss is accomplished via the foliage and it is an effective technique when used with conifers (McMinn 1986). Transpirational drying also seems to be the fastest and easiest method by which delayed processing of felled trees can reduce their wood moisture content (Garrett 1981, McMinn 1986, Wells 1984). The moisture content of various parts of a tree and such factors as temperature and relative humidity have no statistically significant association with bearing on moisture content lost (Wells 1984). Moreover, climatic regimes existing near the forest floor and the moisture loss of the stem and branch of felled trees during summer and fall periods show no statistically significant association (Wells 1984).

Research results indicate that a decrease in moisture content of loblolly pine (whole tree) occurs when it is allowed to dry in piles, even during wet periods. A six to seventy percent reduction in moisture can be realized depending on species and geographic location, if materials are allowed to lie in the woods during winter for ten to twelve weeks after harvesting (Rogers 1981).

Finally, in a project titled "Evaluation of Field Drying of Felled and Bunched Lodgepole pine and Ponderosa Pine Whole Trees," Burke and Uzoh (1987) contend that the location of the trees within the bundle did not affect their drying rates, regardless of the time of harvest. Further, the thin-barked lodgepole pine loses moisture more rapidly than the thick-barked ponderosa pine, but in the event of precipitation, the thin bark species will gain and lose moisture relatively faster, while the reverse is true for thick-bark species.

PROCEDURES

This study was carried out at the Lubrecht Experimental Forest, 30 miles east of Missoula. The study commenced (harvest operations and moisture content sampling) on August 1, 1986 (year date 213) and ended on September 12, 1986 (year date 255).

A. CONSTRUCTION PLAN

1. Construction of a sprinkler system that is sixty-four feet long, with a water outlet (sprinkler) at every eight-foot interval. Graduated cylinders were randomly positioned within the sprinkler system frame This was used to calculate how long it would take the system to produce a quarter inch of shower.
2. Two wood frame sheds measuring sixty-four feet by twenty feet were constructed. The sheds were roofed with transparent plastic sheets. To simulate actual harvest situations, the sheds were built in stands of commercially thinned density area, with openings between live trees, similar to most chipping landings. (Photos 1 and 2).

Photo 1. Shed for watered treatments.

Photo 2. Shed for unwatered treatments.

B. HARVEST OPERATIONS

Live trees of lodgepole pine (*Pinus contorta* Dougl. ex Laud.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) between six and eight inches diameter at breast height (dbh) were harvested. Twelve trees of each species were cut; six of the trees were limbed, while the six others remained unlimbed. Three limbed and three unlimbed of each of the species were kept in each of the sheds. The sprinkler system was housed in one of the sheds. This device compared with the other structure without a sprinkler system helped monitor the effects of precipitation on transpirational drying.

C. MOISTURE CONTENT SAMPLING

After the trees had been transported to the two sheds, two core samples were taken at two locations on the trees, with the aid of a 0.25-inch increment borer. The first sample point was four feet from the cut end of the tree, while the second sample was taken at the first live branch of the trees. Cores were extended into the pith with heartwood separated from sapwood to present an accurate description of the radial moisture distribution. After sampling, holes were plugged with wooden dowels to minimize moisture loss. Cores were sealed in airtight vials and quickly processed to ensure accurate measurement of moisture content.

Weekly sampling was followed immediately with application of 0.25 inch of precipitation, the average for the Lubrecht Experimental Forest and nearby areas. The entire process was repeated at weekly intervals for a period of six weeks.

The samples were subsequently placed in an oven at a temperature of $105^{o}C$ +/- $3^{o}C$ for a period of twenty-four hours. Reweighing of the core samples, determined their oven-dry weight. Once the samples were out of the oven, they were carefully handled, care is needed as much as minimal delay to avoid moisture absorption in the process of reweighing.

The weight difference was used in the calculation of percentage of the moisture content relative to the wet-weight of the core samples.

EQUATION FOR PERCENT MOISTURE CONTENT WET-BASIS

$$\% \, MC = \frac{W - D}{W} (100)$$

Where

$\%$ MC = Percent moisture content wet-basis

W = Green weight of core samples

D = Oven-dry weight of core samples

D. STATISTICAL ANALYSIS

Significant difference in drying rates of the various treatments were determined through analysis of variance (ANOVA). Below is the study/experimental design showing sources of variation and the construction of the F-ratios.

The various treatment combinations (TC) in the analysis are as follows:

TC	DESCRIPTION
1	Watered unlimbed Dougas-fir
2	Watered limbed Douglas-fir
3	Unwatered unlimbed Douglas-fir
4	Unwatered limbed Douglas-fir
5	Watered unlimed lodgepole pine
6	Watered limbed lodgepole pine
7	Unwatered unlimbed lodgepole pine
8	Unwatered limbed lodgepole pine

All references to statistically significant differences between means are denoted at the percent level.

E. GRAPHICAL ANALYSIS

Moreover, graphs of moisture content against dates during which the samples were collected were constructed to indicate the drying rates of the various treatments. Further, the Bonferroni confidence limits were calculated to show the variabilities in mean moisture contents. In addition, the OCP--or the period of time from harvest to the point where desorption of water from the log through transpirational drying is greater than or equal to absorption of precipitation by the log--was also determined from each graph.

Bonferroni formula (from Byrkit 1987):

$\overline{X} \pm t \quad S/\sqrt{n}$

Where

$\overline{X}$ = sample mean MC

t = t_{n-1}, α^* ; $n = 12$ (student's t value)

s = standard deviation

n = number of observations

α^* = α/P

P = number of comparisons

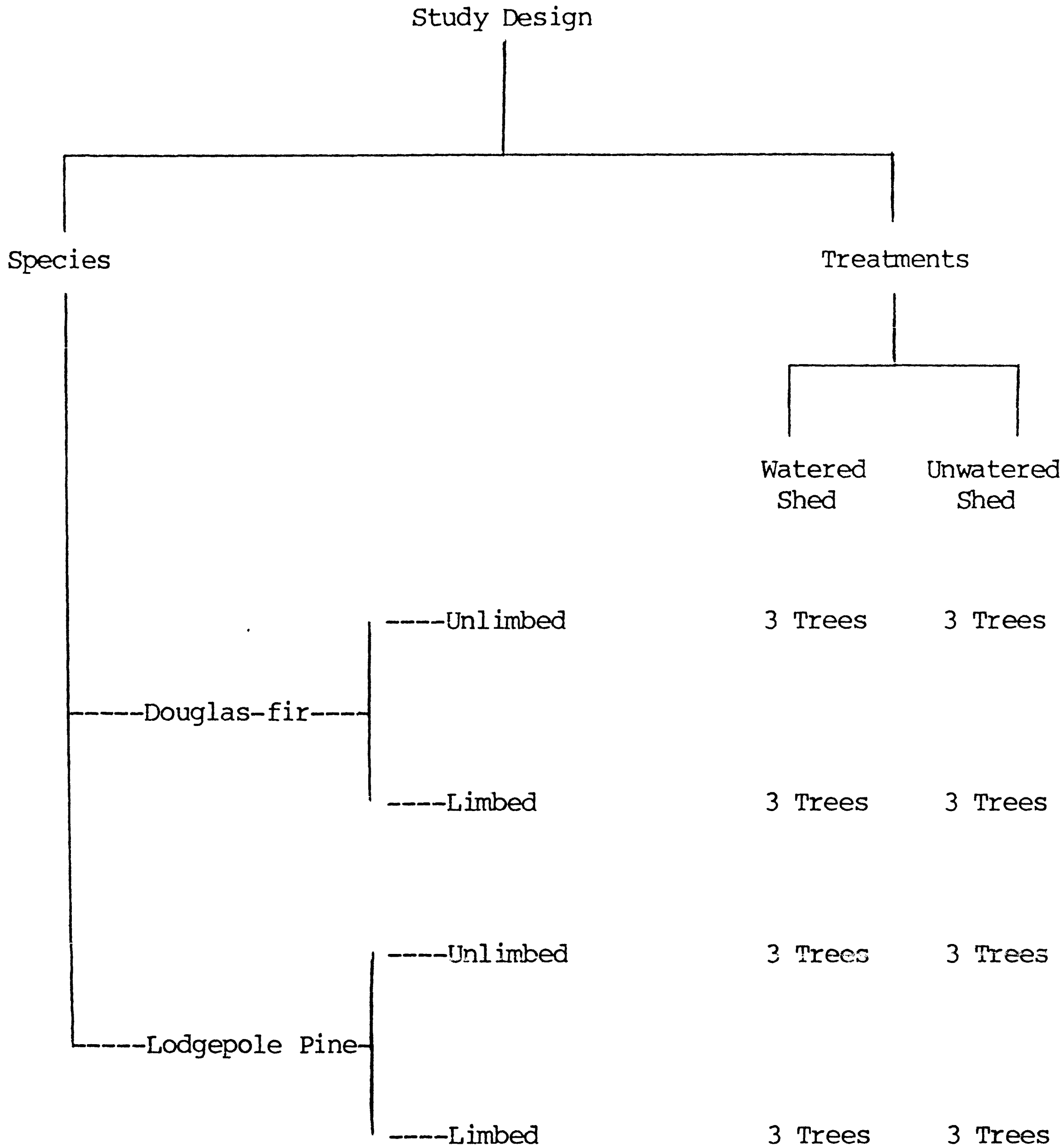

Figure 1. Flow chart of treatment combinations.

Table 1. ANOVA Design.

Source	DE	F-Value
Tree (T)	2	
Treatment (W)	1	
Site (S)	1	
Sample (R)	1	
Date (D)	6	
2-Way interactions		
T x W	2	
T x S	2	
T x R	2	
T x D	12	
W x S	1	
W x R	1	
W x D	6	
S x R	1	
S x D	6	
R x D	6	
Residual	117	
Total	167	

RESULTS & DISCUSSION

A. ANALYSIS OF VARIANCE

1. The mean moisture content of watered unlimbed Douglas-fir was not significantly different from that of unwatered unlimbed Douglas-fir (Table 2-A). This was also shown in Table 6-A. The two treatments--columns 1 and 3--have an average column mean of 11.1389 and 10.9155, respectively.
2. The mean moisture contents between dates, ignoring all other factors, were significantly different. As shown in Table 6-A, the moisture content at various dates were different because the trees were constantly losing moisture.
3. The mean moisture contents between trees, ignoring all other factors, were significantly different. This fact was also supported by Table 4-A. As contained in the table (Table 4-A), the mean tree moisture content for the various treatments were different. They range from 31.81 to 41.69.
4. Due to the significant moisture content differences between trees, the interaction between treatments and trees was also significant, suggesting a differential influence on moisture content of watered unlimbed Douglas-fir vs unwatered unlimbed Douglas-fir across the factor tree. As evident in

Table 4-A, the mean trees' moisture content were different for the two treatments.

5. Due to the significant moisture content differences between dates, the interaction between treatments and date is also statistically significant. This fact was also shown in Table 6-A--columns 1 and 3--the moisture content of the watered unlimbed Douglas-fir decreased over time, but at a slower rate than unwatered unlimbed Douglas-fir.

6. A significant differential influence on moisture content of the factor tree over date was detected. Obviously, since there was a significant moisture content difference between dates, the interaction between tree and date was also statistically significant.

Table 2-A. Analysis of variance of watered unlimbed Douglas-fir vs unwatered unlimbed Douglas-fir.

Source of Variation	Sum of Squares	DF	F-Value	Significance of F
Tree	900.857	2	11.712	0.000
Treatment	62.322	1	1.621	0.206
Site	116.905	1	3.040	0.084
Sample	7.997	1	0.208	0.649
Date	6570.675	6	28.475	0.000
2-Way Interactions:				
Treatment x Tree	771.150	2	10.026	0.000
Treatment x Site	8.701	1	0.226	0.635
Treatment x Sample	0.002	1	0.000	0.995
Treatment x Date	598.832	6	2.595	0.021
Tree x Site	41.736	2	0.543	0.583
Tree x Sample	24.645	2	0.320	0.726
Tree x Date	887.763	12	1.924	0.038
Site x Sample	9.780	1	0.254	0.615
Site x Date	437.515	6	1.896	0.087
Sample x Date	148.017	6	0.641	0.697
Residual	4499.595	117		

7. The main effects of treatment, tree, site, and date were all statistically significant, suggesting a differential influence on moisture content of watered unlimbed lodgepole pine vs unwatered unlimbed lodgepole pine across the above mentioned factors (Table 2-B). This fact was supported by Table 6-B--columns 5 and 7--because the moisture content of the watered unlimbed lodgepole pine decreased over time, but at a slower rate than unwatered unlimbed lodgepole pine. It is necessary to note also that the trees were constantly losing moisture.
8. Due to the significant moisture content differences between the main effects of treatments and dates, the interaction between treatment and date was also significant.

Table 2-B. Analysis of variance of watered unlimbed lodgepole pine vs unwatered unlimbed lodgepole pine.

Source of Variation	Sum of Squares	DF	F-Value	Significance of F
Tree	551.039	2	6.350	0.002
Treatment	1357.220	1	31.279	0.000
Site	195.566	1	4.507	0.036
Sample	0.624	1	0.014	0.905
Date	3728.512	6	14.321	0.000
2-Way Interactions:				
Treatment x Tree	119.999	2	1.383	0.255
Treatment x Site	10.137	1	0.234	0.630
Treatment x Sample	25.363	1	0.585	0.446
Treatment x Date	2621.694	6	10.070	0.000
Tree x Site	205.830	2	2.372	0.098
Tree x Sample	32.287	2	0.372	0.690
Tree x Date	506.946	12	0.974	0.478
Site x Sample	3.551	1	0.082	0.775
Site x Date	553.459	6	2.126	0.055
Sample x Date	124.825	6	0.479	0.823
Residual	5076.791	117		

9. A significant difference in mean moisture content due to treatment, ignoring all other factors (Table 3-A), was detected. As evident in Table 6-A--columns 2 and 4--the moisture content of the watered limbed Douglas-fir decreased over time, but at a slower rate than unwatered limbed Douglas-fir.
10. A statistically significant difference in mean moisture content due to trees, ignoring all other factors was observed. This fact was also supported by Table 5-A because the two treatments have different mean tree moisture content, ranging from 36.67 to 48.53.
11. A significant difference in mean moisture content due to date, ignoring all other factors was observed. This was due to the fact that the trees were constantly losing moisture.
12. Due to the significant moisture content differences of the main effects of treatment, tree, and date, their interactions--treatment by tree, treatment by date, tree by date, and site by date--were also statistically significant, suggesting a differential influence on moisture content of watered limbed Douglas-fir vs unwatered limbed Douglas-fir across the factors treatment, tree, and date.

Table 3-A. Analysis of variance of watered limbed Douglas-fir vs unwatered limbed Douglas-fir.

Source of Variation	Sum of Squares	DF	F-Value	Significance of F
Tree	782.855	2	7.350	0.001
Treatment	731.812	1	13.742	0.000
Site	0.952	1	0.018	0.894
Sample	0.824	1	0.015	0.901
Date	5096.300	6	15.950	0.000
2-Way Interactions:				
Treatment x Tree	965.068	2	9.061	0.000
Treatment x Site	1.085	1	0.020	0.887
Treatment x Sample	58.252	1	1.094	0.298
Treatment x Date	1499.736	6	4.694	0.000
Tree x Site	19.667	2	0.185	0.832
Tree x Sample	75.020	2	0.704	0.496
Tree x Date	2576.864	12	4.032	0.000
Site x Sample	1.525	1	0.029	0.866
Site x Date	759.360	6	2.377	0.033
Sample x Date	191.871	6	0.601	0.729
Residual	6230.530	117		

13. The mean moisture content of watered limbed lodgepole pine was not significantly different from that of unwatered limbed lodgepole pine (Table 3-B). This fact was evident in Table 6-B--columns 6 and 8--the moisture content of the watered limbed and unwatered limbed lodgepole pine decreased at the same rate. Further, their average mean column moisture contents were 12.7093 and 12.9877, respectively, suggesting no difference between the two treatments.

14. A significant difference in mean moisture content due to trees, ignoring all other factors, was detected. As shown in Table 5-B, the trees' mean moisture content for the two treatments ranged from 48.53 to 36.67, thus suggesting a big difference between the two treatments. The same was true for the main effect, site.

15. The main effect, date, also showed a statistically significant difference in moisture content. This is due to the fact that the trees were constantly losing moisture.

16. As a result of the fact that the main effect tree and date were statistically significant, their interactions--treatment by tree and treatment by data--were also significant, suggesting a differential influence on moisture content of

watered limbed lodgepole pine vs unwatered limbed lodgepole pine across the factors tree and date.

Table 3-B. Analysis of variance watered limbed lodgepole pine vs unwatered limbed lodgepole pine.

Source of Variation	Sum of Squares	DF	F-Value	Significance of F
Tree	475.001	2	5.804	0.004
Treatment	6.381	1	0.156	0.694
Site	181.451	1	4.434	0.037
Sample	54.372	1	1.329	0.251
Date	1360.741	6	5.542	0.000
2-Way Interactions:				
Treatment x Tree	1555.550	2	19.008	0.000
Treatment x Site	59.121	1	1.445	0.232
Treatment x Sample	1.755	1	0.043	0.836
Treatment x Date	897.271	6	3.655	0.002
Tree x Site	234.464	2	2.865	0.061
Tree x Sample	120.443	2	1.472	0.234
Tree x Date	658.789	12	1.342	0.205
Site x Sample	0.131	1	0.003	0.955
Site x Date	238.618	6	0.972	0.447
Sample x Date	124.846	6	0.509	0.801
Residual	4787.508	117		

Table 4-A. Mean moisture contents of treatment by tree watered unlimbed Douglas-fir (treatment 1) vs unwatered unlimbed Douglas-fir (treatment 3).

	Tree		
Treatment	1	2	3
1	36.88	35.54	39.57
3	41.69	31.81	34.84

Table 4-B. Mean moisture contents by treatment by tree watered unlimbed lodgepole pine (treatment 5) vs unwatered unlimbed lodgepole pine (treatment 7).

	Tree		
Treatment	1	2	3
5	38.17	39.36	36.98
7	32.04	35.93	29.48

Table 5-A. Mean moisture contents of treatment by tree watered limbed Douglas-fir (treatment 2) vs unwatered limbed Douglas-fir (treatment 4).

	Tree		
Treatment	4	5	6
2	39.41	45.39	48.53
4	41.87	36.67	42.27

Table 5-B. Mean moisture contents of treatment by tree watered limbed lodgepole pine (treatment 6) vs unwatered limbed lodgepole pine (treatment 8).

	Tree		
Treatment	4	5	6
6	42.19	43.64	40.31
8	41.55	35.92	47.49

Table 6-A. Mean and standard deviation of mean moisture content by dates and treatments for Douglas-fir.

	Mean Std.Dev.	Treatments[1] 1	2	3	4	Row Total
Date						
213	1	20.0566	26.0429	22.5674	22.0591	22.6815
		3.8426	5.1906	6.0122	3.3476	5.0587
220	2	11.4958	11.3299	10.9356	11.9806	11.4355
		2.1566	2.1879	1.7822	1.4907	1.9015
227	3	10.0084	11.0497	8.8013	10.3552	10.0536
		2.0079	2.5308	1.6452	1.2903	2.0355
234	4	8.7957	10.3058	10.0368	10.1389	9.8193
		2.2772	2.7479	1.4382	1.8489	2.1520
241	5	9.7154	8.4931	8.4863	9.7084	9.1008
		1.2705	2.6944	1.1247	2.1160	1.9499
248	6	9.4058	9.8184	8.6659	8.5147	9.1012
		1.4094	2.6706	1.3086	2.5661	2.0898
255	7	8.4944	9.7272	6.9151	7.7886	8.2313
		2.4705	1.6843	1.8524	2.2508	2.2721
Column Total		11.1389	12.3953	10.9155	11.5065	11.4890
		4.7948	6.3651	5.5659	4.9945	5.3850

[1]Treatment #1 = watered unlimbed
Treatment #2 = watered limbed
Treatment #3 = unwatered unlimbed
Treatment #4 = unwatered limbed

Table 6-B. Mean and standard deviation of mean moisture content by dates and treatments for lodgepole pine.

	Mean Std.Dev.	Treatments[1] 5	6	7	8	Row Total
Date						
213	1	23.9781	22.6545	19.8835	23.9515	22.6169
		3.3391	2.3966	4.6902	3.2599	3.7980
220	2	11.2913	9.8707	9.6778	10.5075	10.3368
		2.0896	1.8270	1.7456	1.9439	1.9512
227	3	7.1560	11.8076	8.9342	12.3116	10.0524
		2.4175	1.8707	2.7038	2.7744	3.4327
234	4	10.8464	11.9930	10.7044	11.9294	11.3683
		.9444	1.7876	1.5552	1.5647	1.5677
241	5	8.8936	10.5559	9.3382	10.0624	9.7125
		1.7722	1.1874	1.5153	2.1940	1.7745
248	6	9.5752	10.7652	7.7340	10.5271	9.6504
		1.0342	1.6132	1.5363	1.9155	1.8977
255	7	8.2398	11.3182	7.8185	11.6145	9.7502
		1.8189	1.8730	1.7211	2.2341	2.5528
Column Total		11.4258	12.7093	10.5844	12.9877	11.9268
		5.6835	4.4990	4.5904	5.1755	5.0819

[1]Treatment #5 = watered unlimbed
Treatment #6 = watered limbed
Treatment #7 = unwatered unlimbed
Treatment #8 = unwatered limbed

B. GRAPHICAL ANALYSIS

The falling and rising of the graphs indicated moisture loss and gain respectively. As shown in figures 1 to 8, the trees which have had various treatments applied to them lost moisture approximately at the same rate. This fact was also supported by the tables--Table 6-A and 6-B--containing moisture content means.

However, within each species, the unlimbed trees, regardless of whether watered or unwatered, lost moisture at a greater rate than their limbed counterparts.

Table 7. The Optimum Chipping Period (OCP) by species and treatments.

Species	Treatments	OCP (In Weeks)
Douglas-fir		
	Watered Unlimbed	1
	Watered Limbed	2
	Unwatered Unlimbed	1
	Unwatered Limbed	2
Lodgepole Pine		
	Watered Unlimbed	1
	Watered Limbed	1
	Unwatered Unlimbed	1
	Unwatered Limbed	1

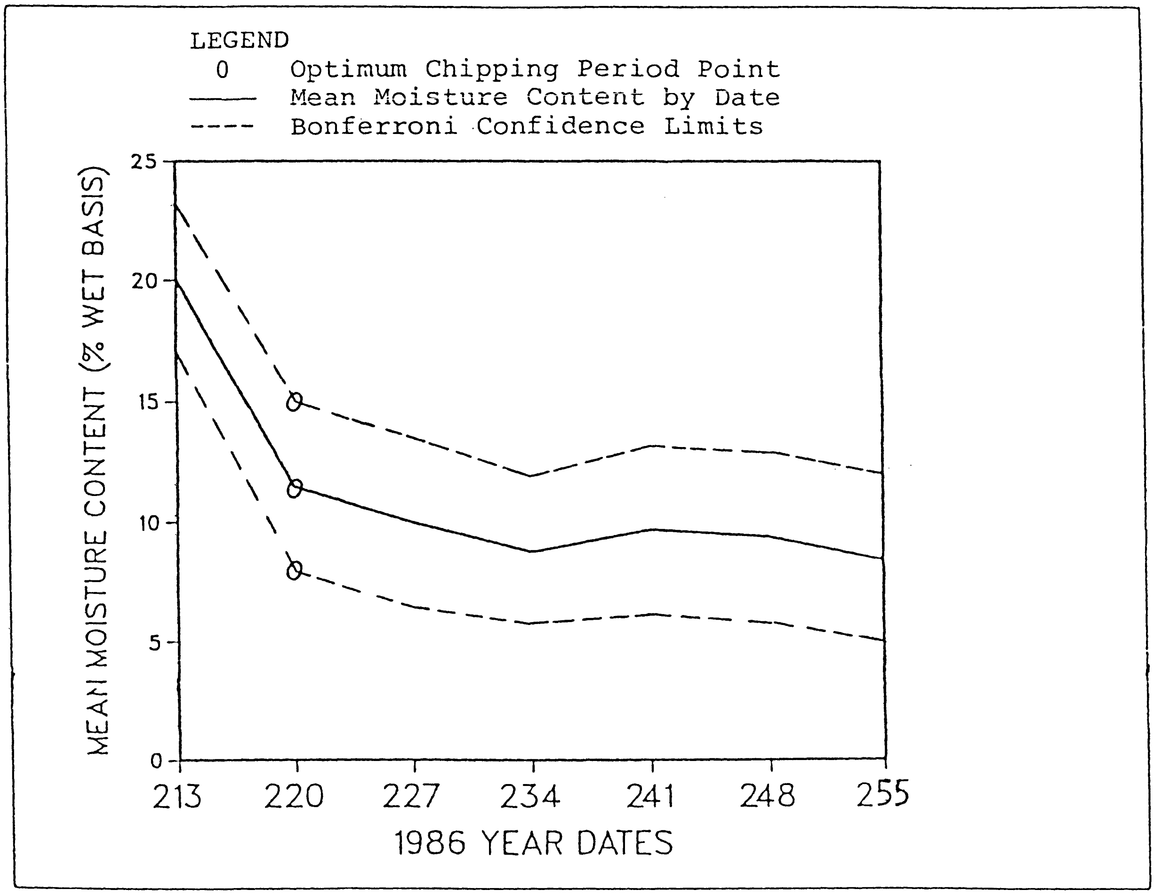

Figure 2. Display of Mean Moisture Content by Date for Watered Unlimbed Douglas-fir.

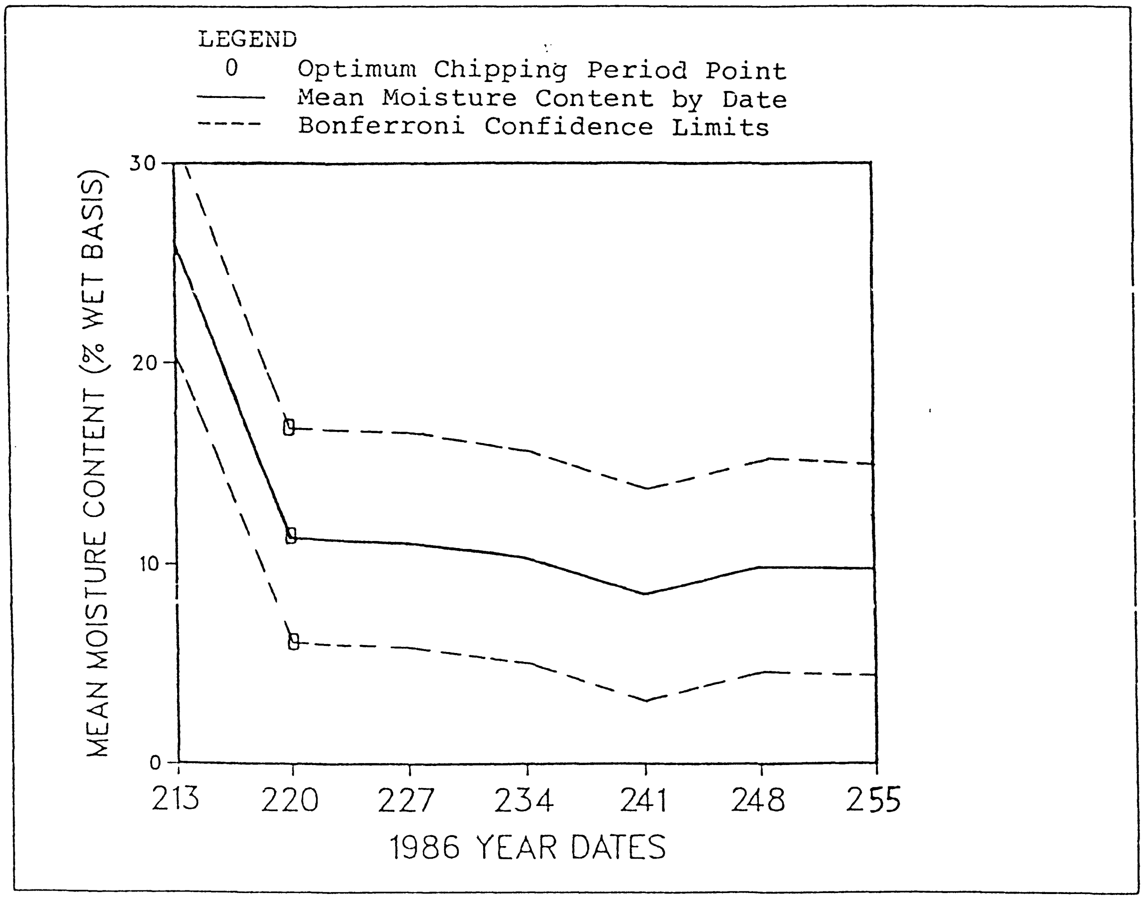

Figure 3. Display of Mean Moisture Content by Date for Watered Limbed Douglas-fir.

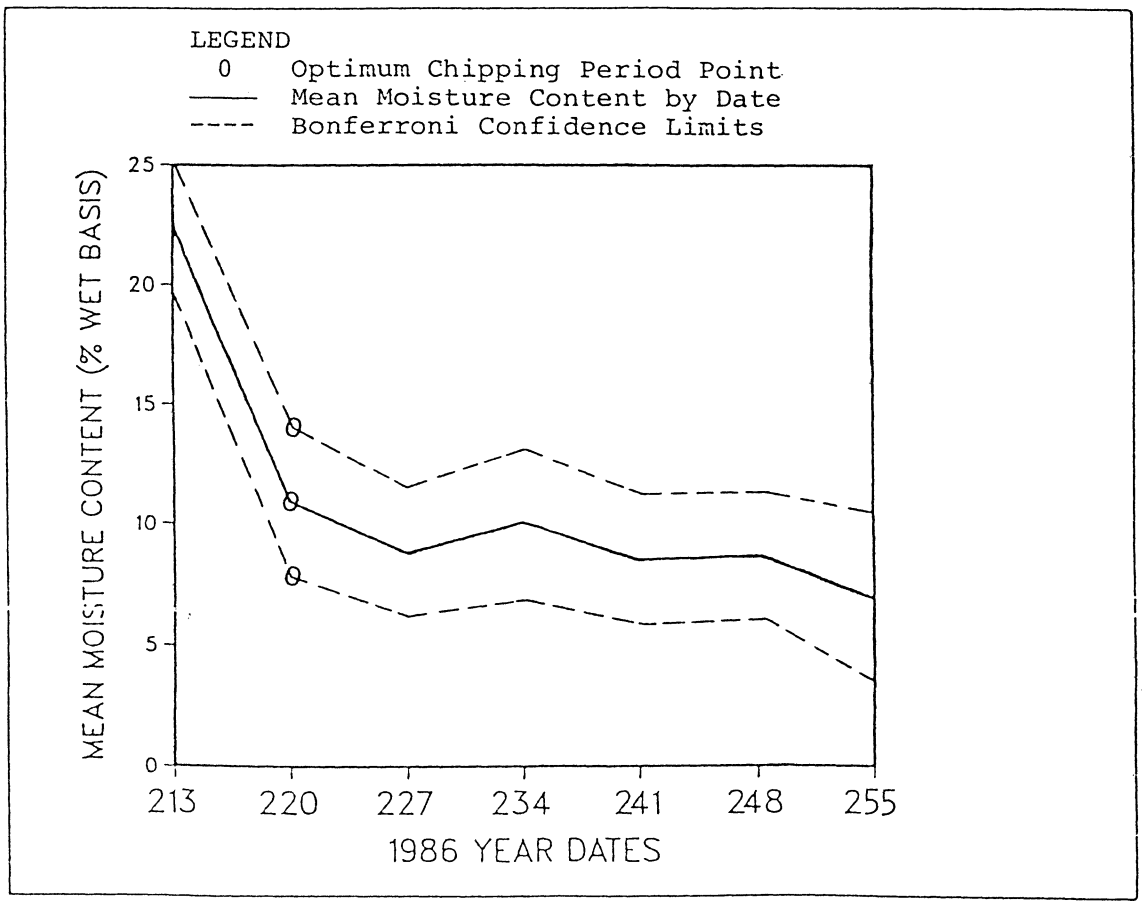

Figure 4. Display of Mean Moisture Content by Date for Unwatered Unlimbed Douglas-fir.

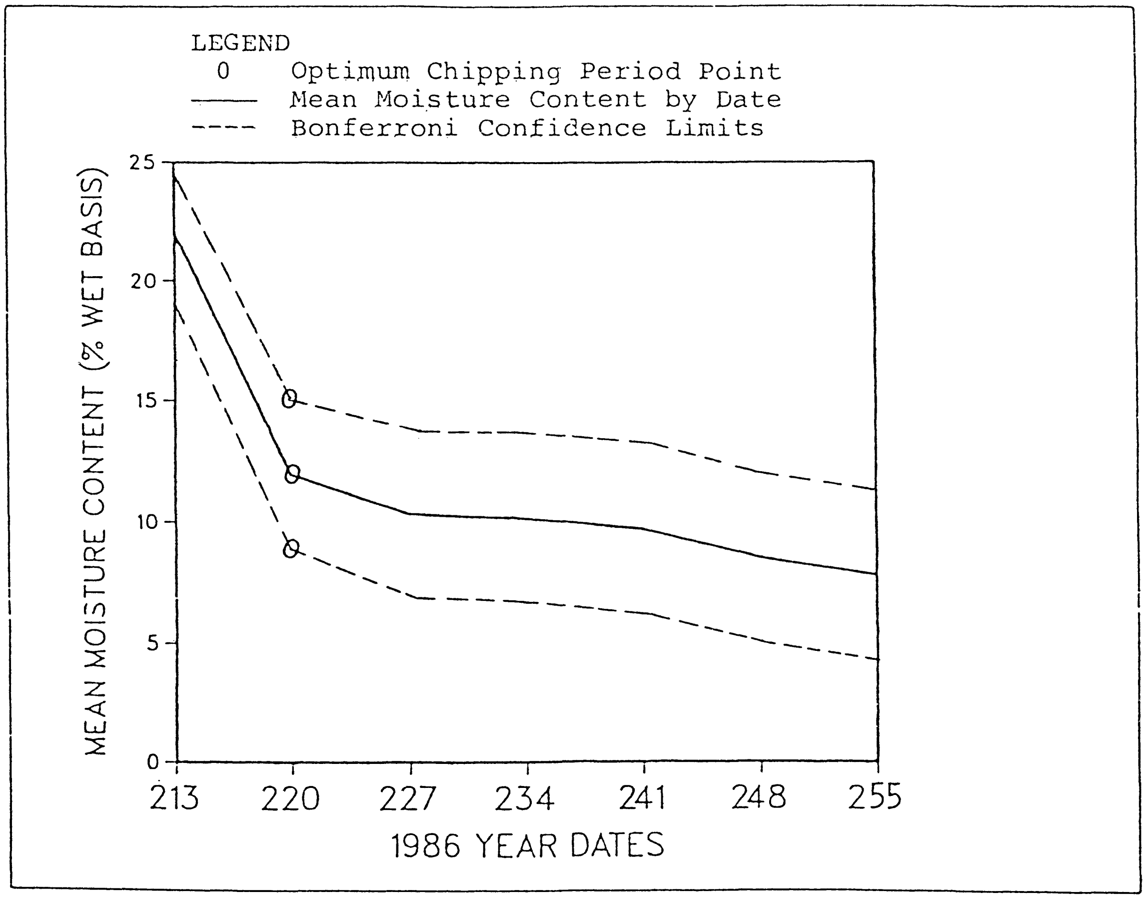

Figure 5. Display of Mean Moisture Content by Date for Unwatered Limbed Douglas-fir.

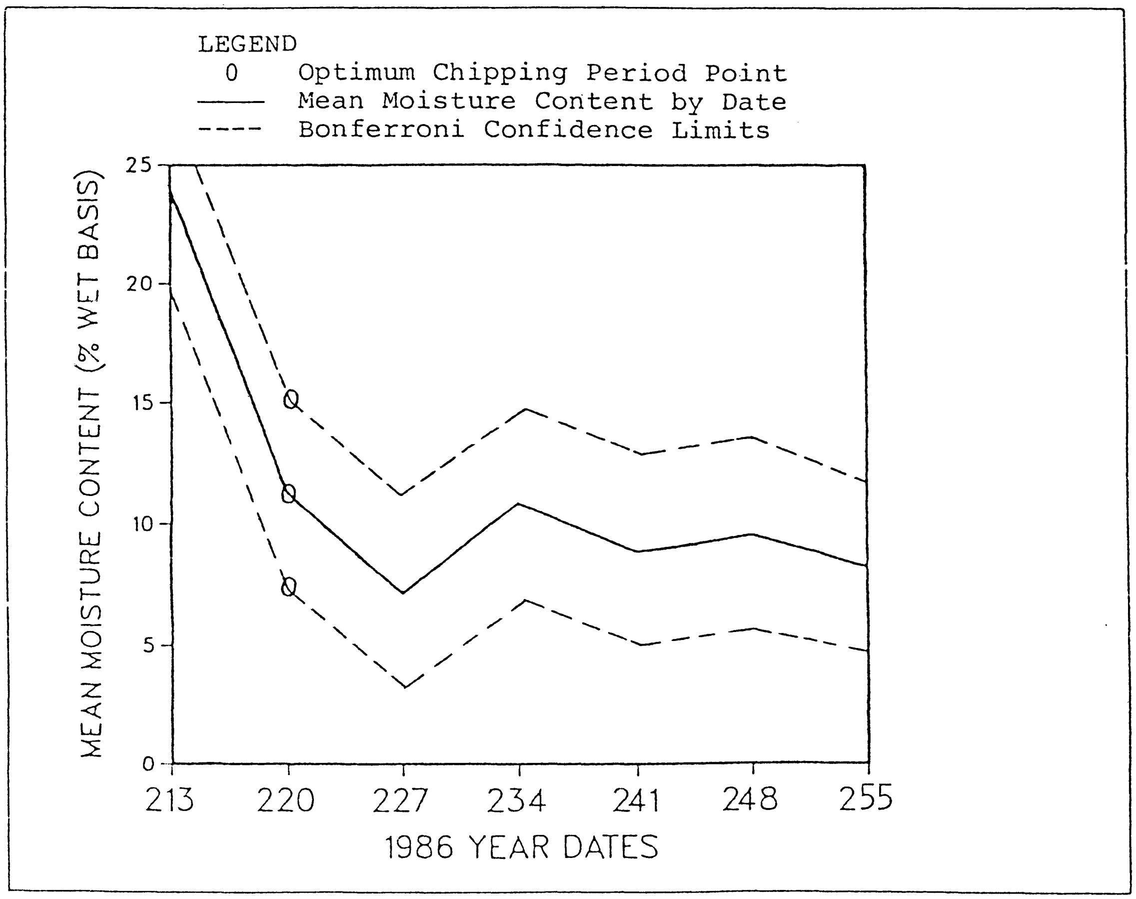

Figure 6. Display of Mean Moisture Content by Date for Watered Unlimbed Lodgepole Pine.

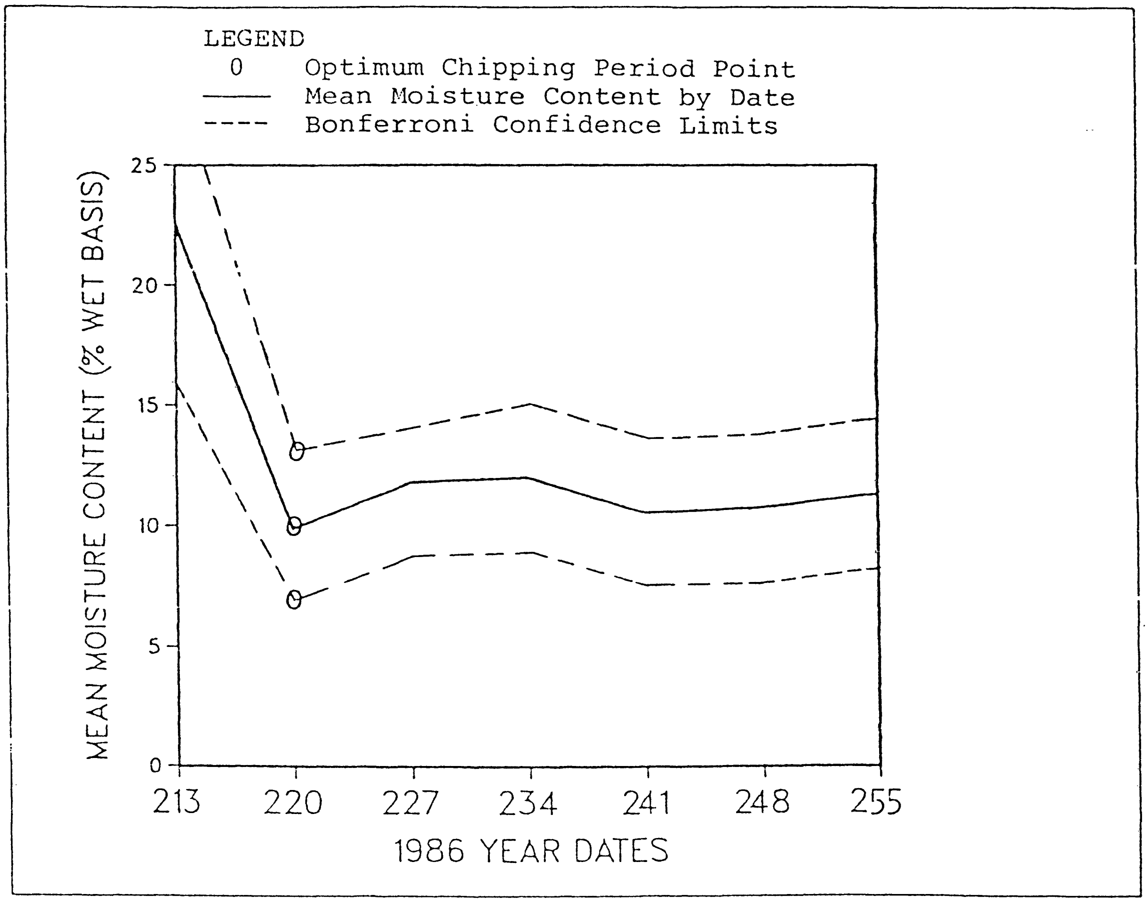

Figure 7. Display of Mean Moisture Content by Date for Watered Limbed Lodgepole Pine.

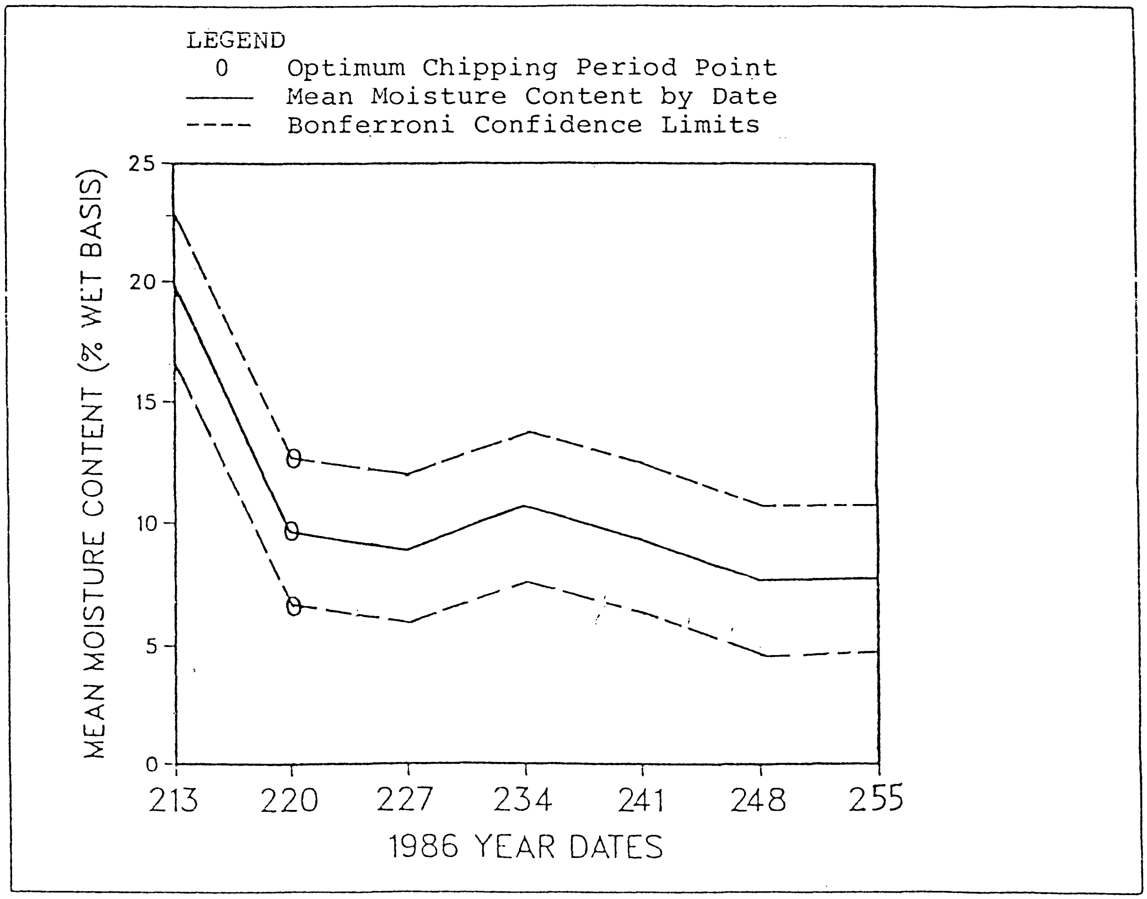

Figure 8. Display of Mean Moisture Content by Date for Unwatered Unlimbed Lodgepole Pine.

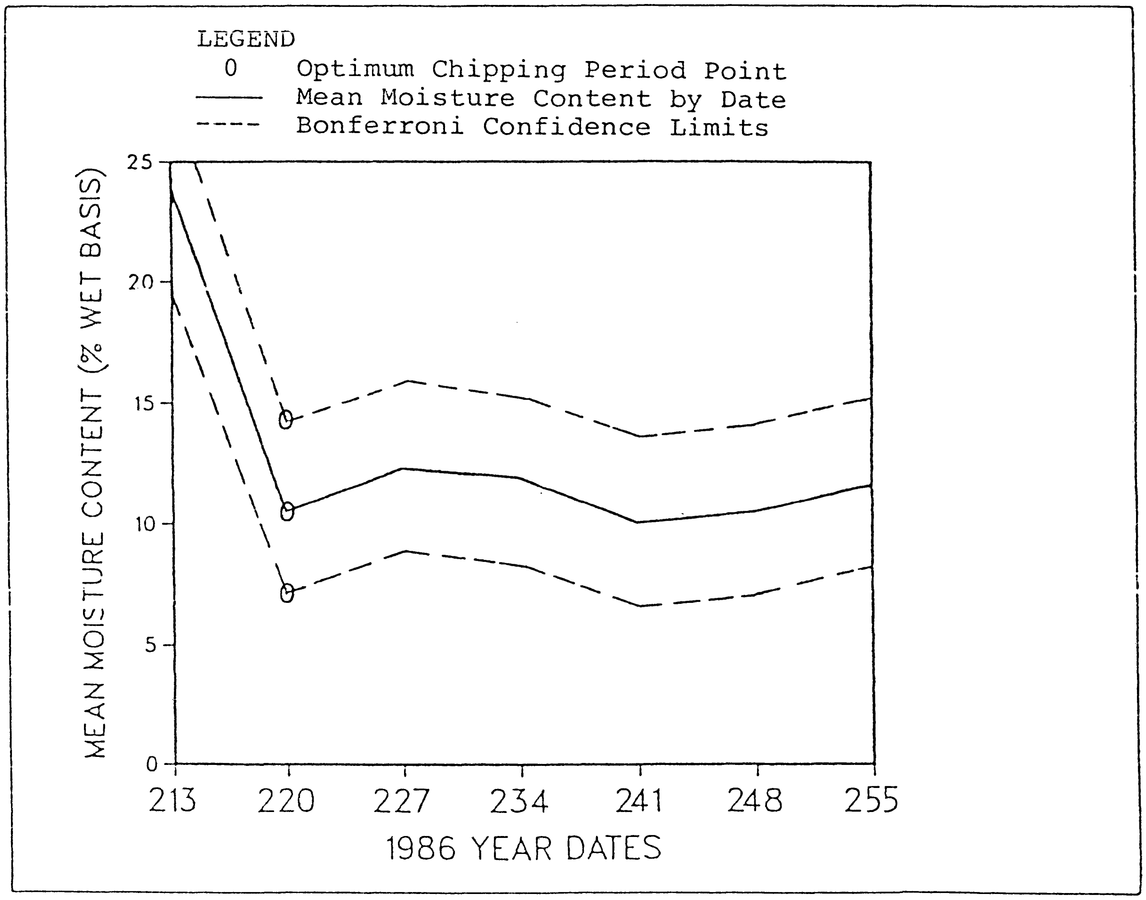

Figure 9. Display of Mean Moisture Content by Date for Unwatered Limbed Lodgepole Pine.

CONCLUSIONS

From the foregoing statistical results, the graphical display of treatments' mean moisture content against dates of sample collections, and from observations made during the course of the research, the following conclusions can be made:

A. DOUGLAS-FIR MOISTURE CONTENT COMPARISONS

1. There was no statistically significant difference in the drying rates of the trees receiving the treatments: Unlimbed and watered or unwatered. However, the drying rates of the individual trees were statistically significant.
2. The unlimbed trees dried faster than the limbed ones because foliage facilitated the drying process of the unlimbed trees.

B. LODGEPOLE PINE MOISTURE CONTENT COMPARISONS

1. The drying rates of the trees receiving the treatments were statistically significant: watered, unwatered, unlimbed, and limbed.
2. Foliage facilitates the drying process of the trees because the unlimbed trees dried faster than the limbed ones--watered and unwatered alike.

C. OPTIMUM CHIPPING PERIOD

From the graphical display of treatments' mean moisture content against date--1986 year dates--the following conclusions can be made:

Regardless of species, watered or unwatered, the unlimbed trees dried faster than their limbed counterparts. Further, the unlimbed trees attained their optimum chipping period (OCP) one week after harvest, while their limbed counterparts reached their OCP between one and two weeks after harvest. Bonferroni confidence limits were used to show the variabilities in mean moisture contents, and defined the limits within which the population mean moisture contents were trapped.

Since this study took place in summer and optimum chipping period may be different for other seasons of the year--more research is needed to determine any seasonal differences in optimum chipping period.

LITERATURE CITED

Burke, E., and F. Uzoh. 1987. (under review). Evaluation of Field Drying of Felled and Bunched Lodgepole Pine and Ponderosa Pine Whole Trees. School of Forestry, University of Montana, Missoula.

Byrkit, D.R. 1987. Statistics Today: A Comprehensive Introduction. Benjamin Cummius Pub. Co., Menlo Park, California. 850 p.

Comstock, G.L. 1976. Energy requirements for drying of wood products. Paper presented during FPRS Energy Workshop on Wood Residue as an Energy Source. Proceedings No. P-75-13. For. Prod. Res. Society, 2801 Marshall Court, Madison, Wisconsin 53705.

Corder, S.E. 1976a. Fuel characteristics of wood and bark and factors affecting heat recovery. Paper presented during FPRS Energy Workshop on Wood Residue as an Energy Source. Proceedings No. P-75-13. For. Prod. Res. Society, 2801 Marshall Court, Madison, Wisconsin 53705.

Corder, S.E. 1976b. Properties and uses of bark as an energy source. Oregon State University, School of Forestry, Corvallis, Oregon. Res. Pap. 31.

Garrett, L.D. 1981. Evaluating feedstock requirements for a 50-megawatt wood-fired electric generating plant. For. Prod. J. 31(1): 26-31.

Garrett, L.D. 1985. Delayed processing of felled trees to reduce wood moisture content. Forest Prod. J. 35(3): 55-59.

Kelsey, R.G., D.P. Lowery and F. Shafizadeh. 1979. Heat content of . bark, twig, and foliage on nine species of western conifers. USDA For. Serv. Res. Note INT-261. Intermt. For. and Range Exp. Stn., Ogden, Utah.

McMinn, J.W. 1986. Transpirational drying of red oaks, sweetgum, and yellow-poplar in the Upper Piedmont of Georgia. Forest Prod. J. 36(3): 25-27.

Rogers, K.E. 1981. Preharvest drying of logging residues. For. Prod. J. 31(12): 32-36.

Sherwood, L., and D. Meadows. 1978. The fuel requirements of a 50-megawatt wood-fired electrical generation facility in northern Vermont. Dartmouth College, Thayer School of Engineering, Hanover, N.H. DSD Rept. 106.

Springer, L. 1980. Should whole-tree chips for fuel be dried before storage? USDA For. Serv. Res. Note FPL-0241. For. Prod. Lab. Madison, Wis., in cooperation with the University of Wisconsin.

Walters, D.F. 1976. Air quality regulations affecting the use of wood residue as fuel. Paper presented during FPRS Energy Workshop on Wood Residue as an Energy Source. Proceedings No. P-75-13. For. Prod. Res. Society, 2801 Marshall Court, Madison, Wisconsin 53705.

Wells, G.C., and R.E. Booker. 1984. Drying logs in the Forest Logging Industry Research Association. Vol. 6 No. 2. New Zealand.